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Antiproton beams: a unique tool to study antihyperons embedded in nuclei

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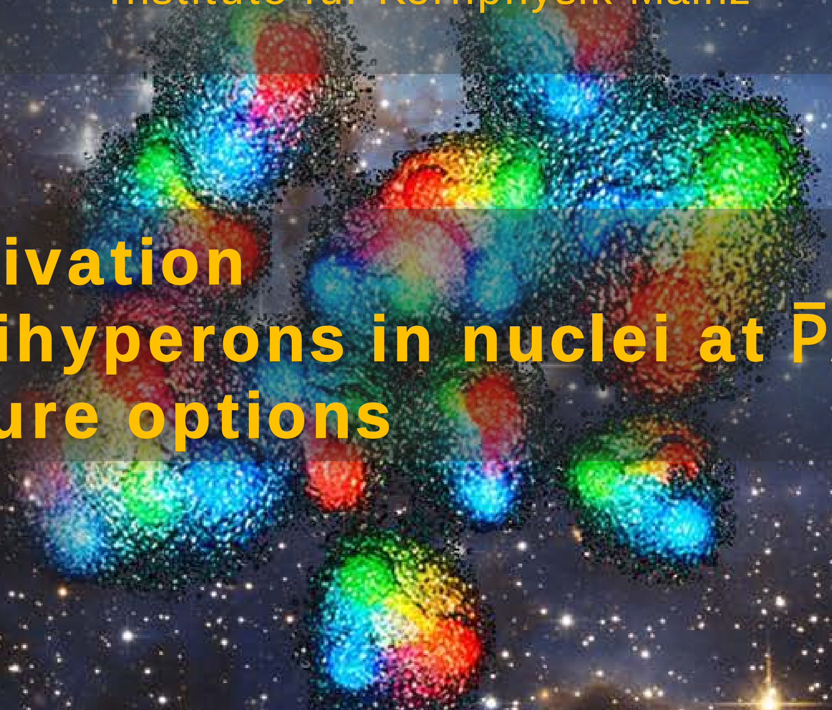
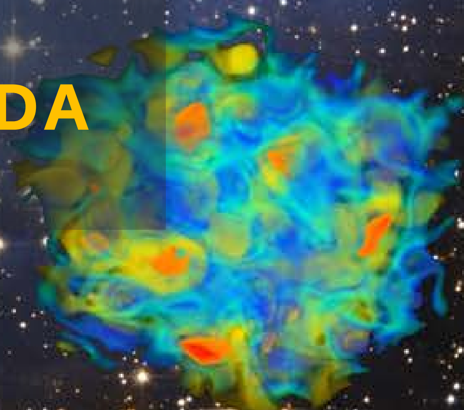


- **Motivation**
- **Antihyperons in nuclei at $\bar{P}$ANDA**
- **Future options**



Antihyperons in Nuclei

- How is g-parity borken? $U(\bar{p})=-150\,\mathrm{MeV}$

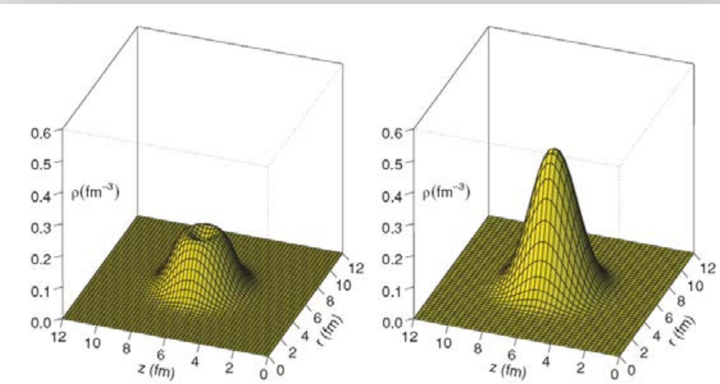
$$G\left|\pi^{\pm 0}\right\rangle = (-1)^1 C\left|\pi^{\pm 0}\right\rangle = -\left|\pi^{\pm 0}\right\rangle$$

$$G\left|\rho\right\rangle = (-1)^1 C\left|\rho\right\rangle = +\left|\rho\right\rangle$$

$$G\left|\omega\right\rangle = (-1)^0 C\left|\omega\right\rangle = -\left|\omega\right\rangle$$

$$G\left|\sigma\right\rangle = (-1)^0 C\left|\sigma\right\rangle = +\left|\sigma\right\rangle$$

- Cold compression by antibaryons?



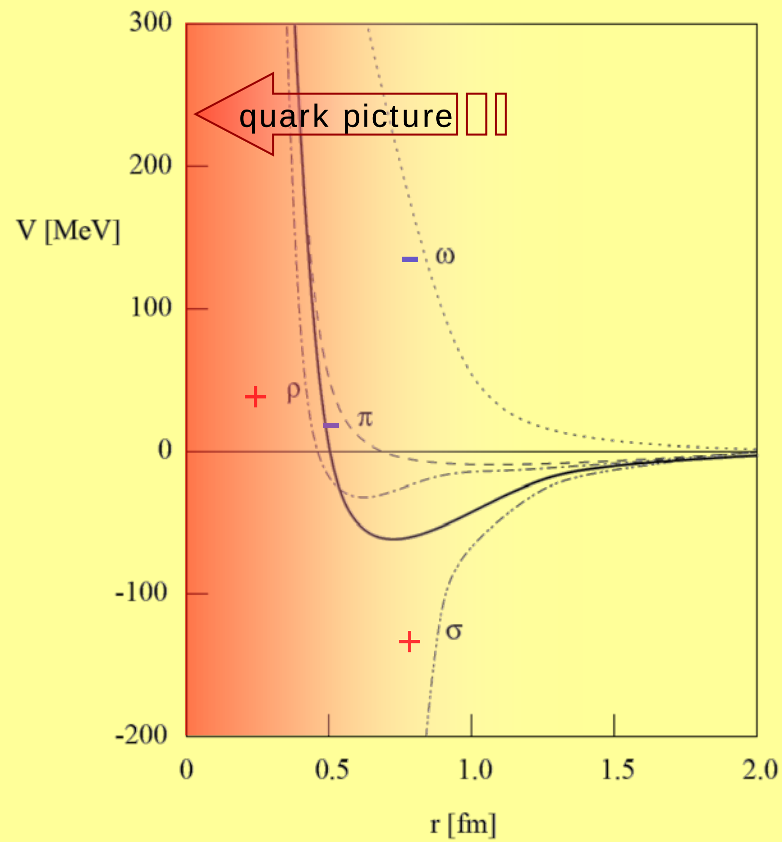
nucleon density in the ^{16}O nucleus (left) and in the bound $\bar{p} + {}^{16}$O system (right)

I. N. Mishustin, L. M. Satarov, T. J. Bürvenich, H. Stöcker, and W. Greiner

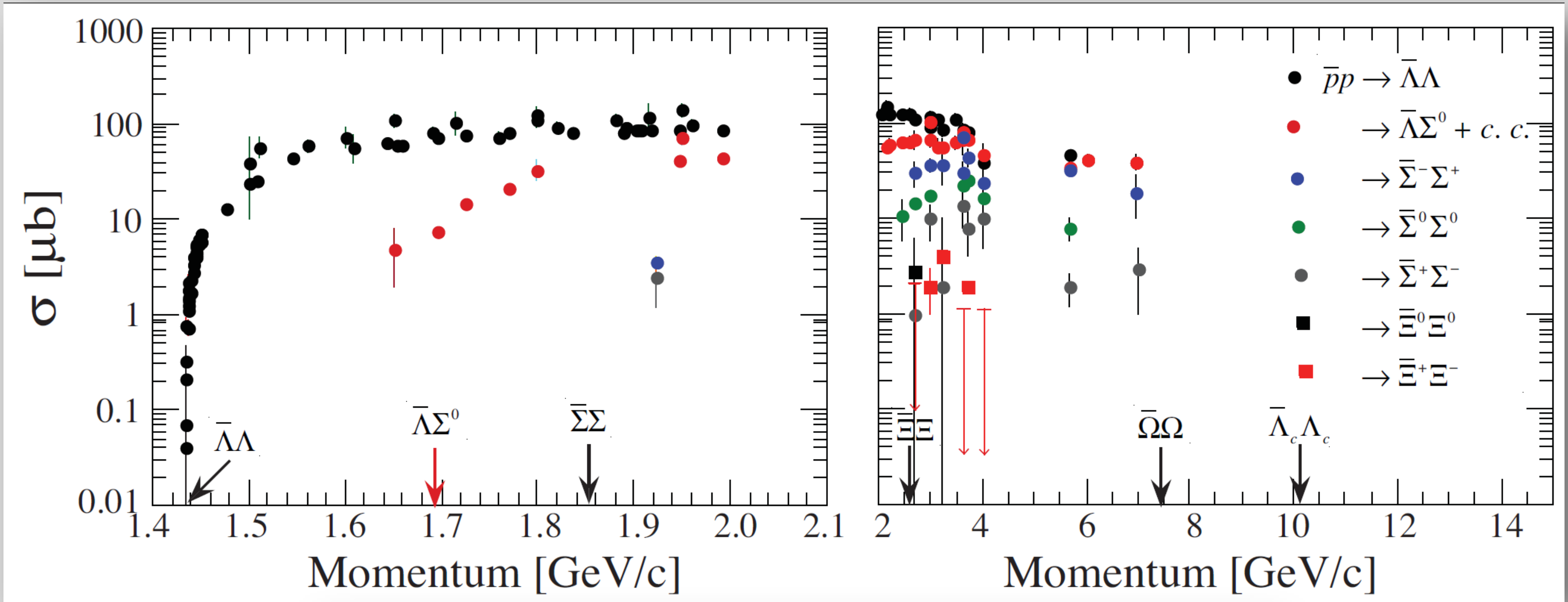
PHYSICAL REVIEW C **71**, 035201 (2005)

Hans-Peter Dürr and Edward Teller, Phys. Rev. **101**, 494 (1956):

sign change in coupling constant when going from NN to N$\bar{\mathrm{N}}$



$\bar{\mathrm{P}}$ANDA – a Factory for strange *and* charmed $Y\bar{Y}$-Pairs

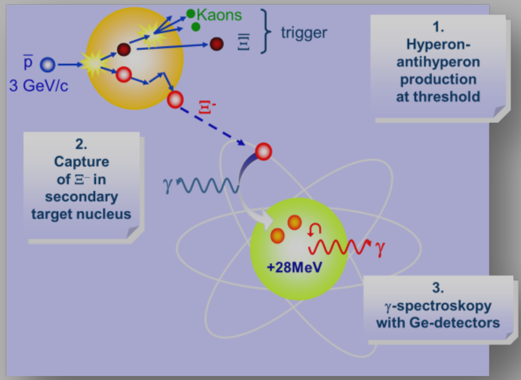


Momentum [GeV/c]	Reaction	Rate [s^{-1}]
1.64	$\bar{p}p \to \Lambda\bar{\Lambda}$	580
4	$\bar{p}p \to \Lambda\bar{\Lambda}$	980
	$\bar{p}p \to \bar{\Xi}^+\Xi^-$	30
15	$\bar{p}p \to \Lambda\bar{\Lambda}$	120

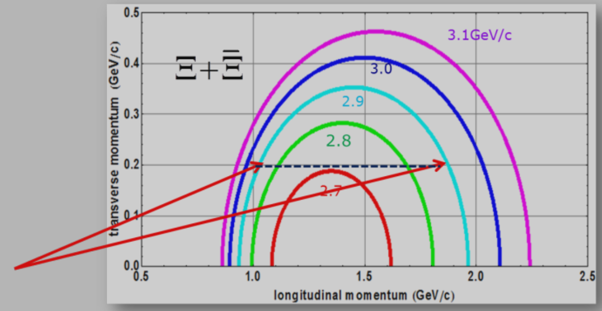
Table 4.45: Estimated count rates into their charged decay mode for the benchmark channels at a luminosity of $2 \cdot 10^{32} cm^{-2} s^{-1}$

Exploring (anti-)hyperon interactions

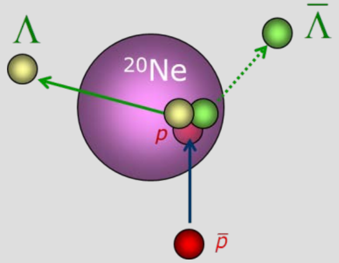
- Excited particle stable state spectroscopy
  - γ-spectroscopy PANDA@FAIR



- Secondary scattering of momentum tagged hyperons and antihyperons



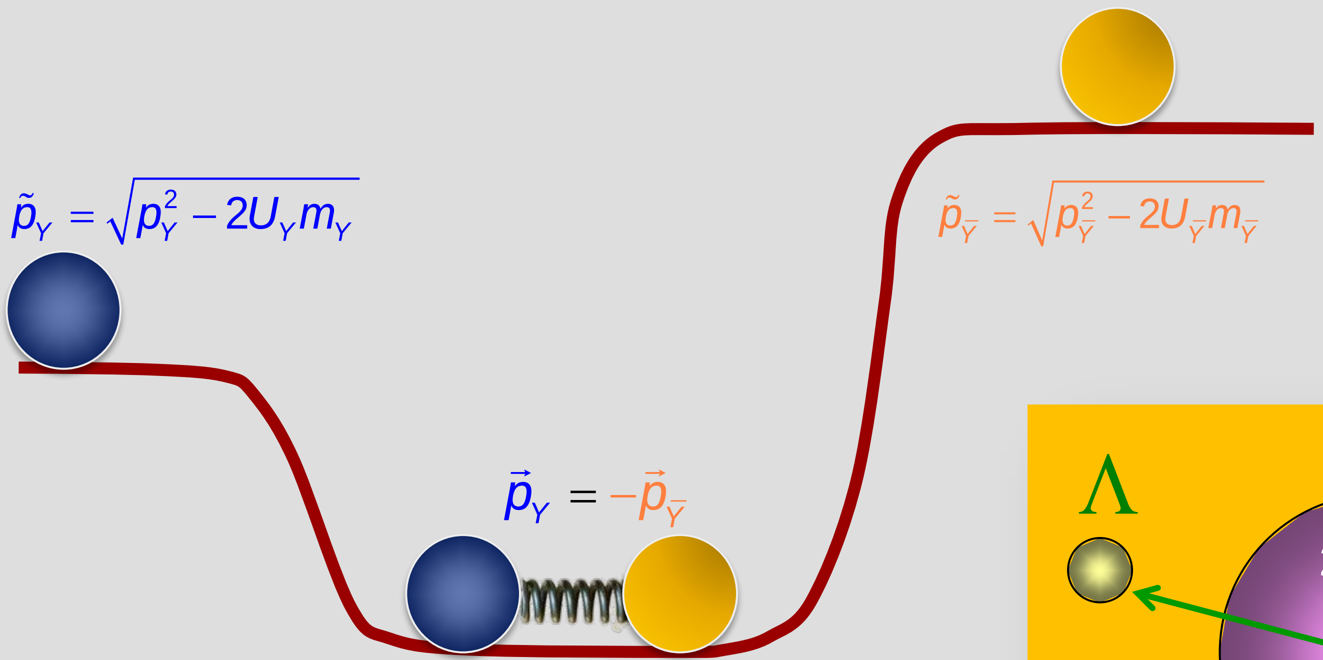
- Antihyperons in atomic nuclei



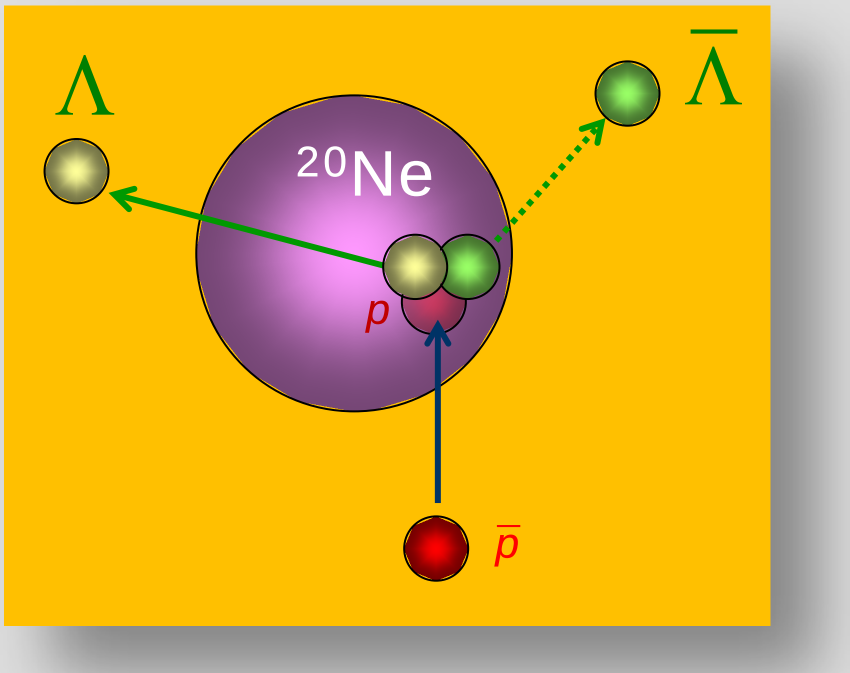

reaching for the unthinkable
ANTIHYPRONS IN NUCLEI
at PANDA

$\overline{\Lambda}$ Potential

- exclusive $\bar{p}+p(A) \rightarrow Y+\bar{Y}$ close to threshold within a nucleus
- Λ and $\overline{\Lambda}$ that leave the nucleus will have different asymptotic momenta depending on the respective potential



J.P., PLB **669** (2008) 306



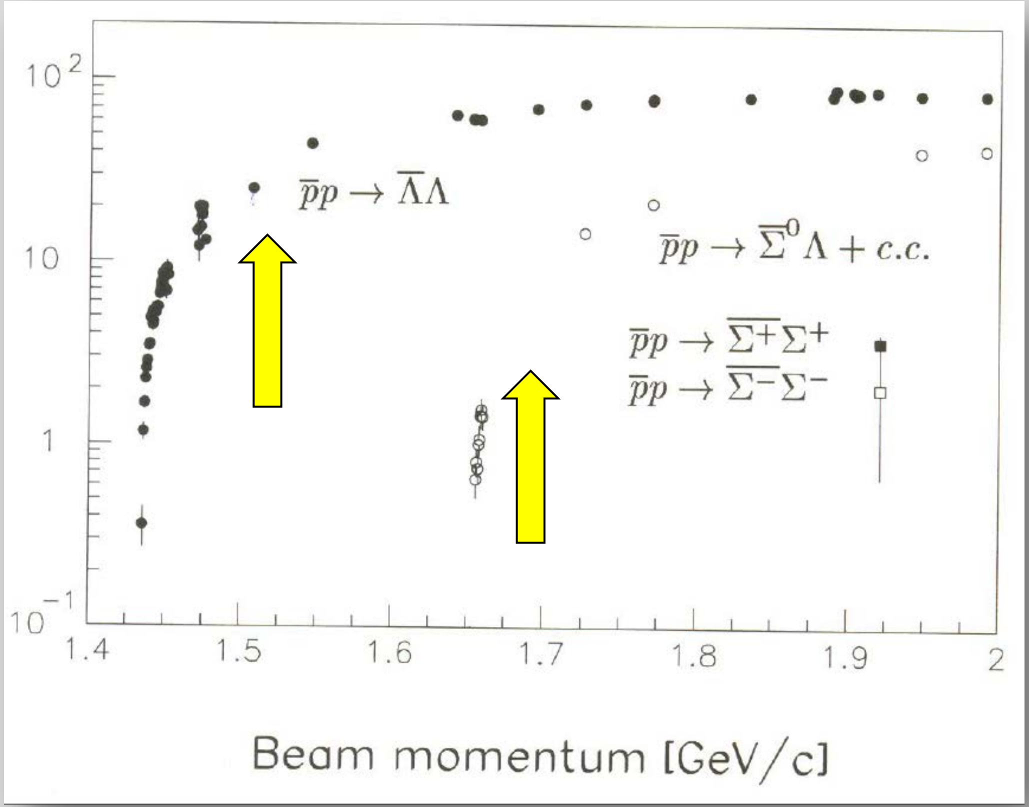
- $\Rightarrow$ *transverse* momentum close to threshold of *coincident* $Y\bar{Y}$ pairs

$$\alpha_\perp = \left\langle \frac{p_\perp(\Lambda) - p_\perp(\overline{\Lambda})}{p_\perp(\Lambda) + p_\perp(\overline{\Lambda})} \right\rangle$$

GiBUU Simulations $\bar{p}+{}^{20}\mathrm{Ne} \rightarrow \Lambda\bar{\Lambda}+X$

- GiBUU
  - G-parity used to estimate anti-baryon potentials except for $\bar{N}$
  - Approximately 15k exclusive $\Lambda\bar{\Lambda}$ pairs in each set
    corresponds to ~15 min P̄ANDA incl. efficiency at $10^7 s^{-1}$

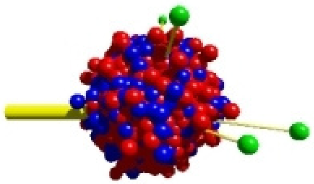
Energy (MeV)	Momentum (MeV/c)	Excess energy (MeV)
850	1522	30.6
1000	1696	92.0



- Aim of the present work
  - Explore sensitivity of α_T to a scaling of the real $\bar{Y}$ potential
  - Proof the feasibility of a measurement at P̄ANDA
  - Trigger a fully self-consistent dynamical treatment of antihyperons in nuclei

GiBUU 1.5

- https://gibuu.hepforge.org/trac/wiki



Institut für Theoretische Physik, JLU Giessen

GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

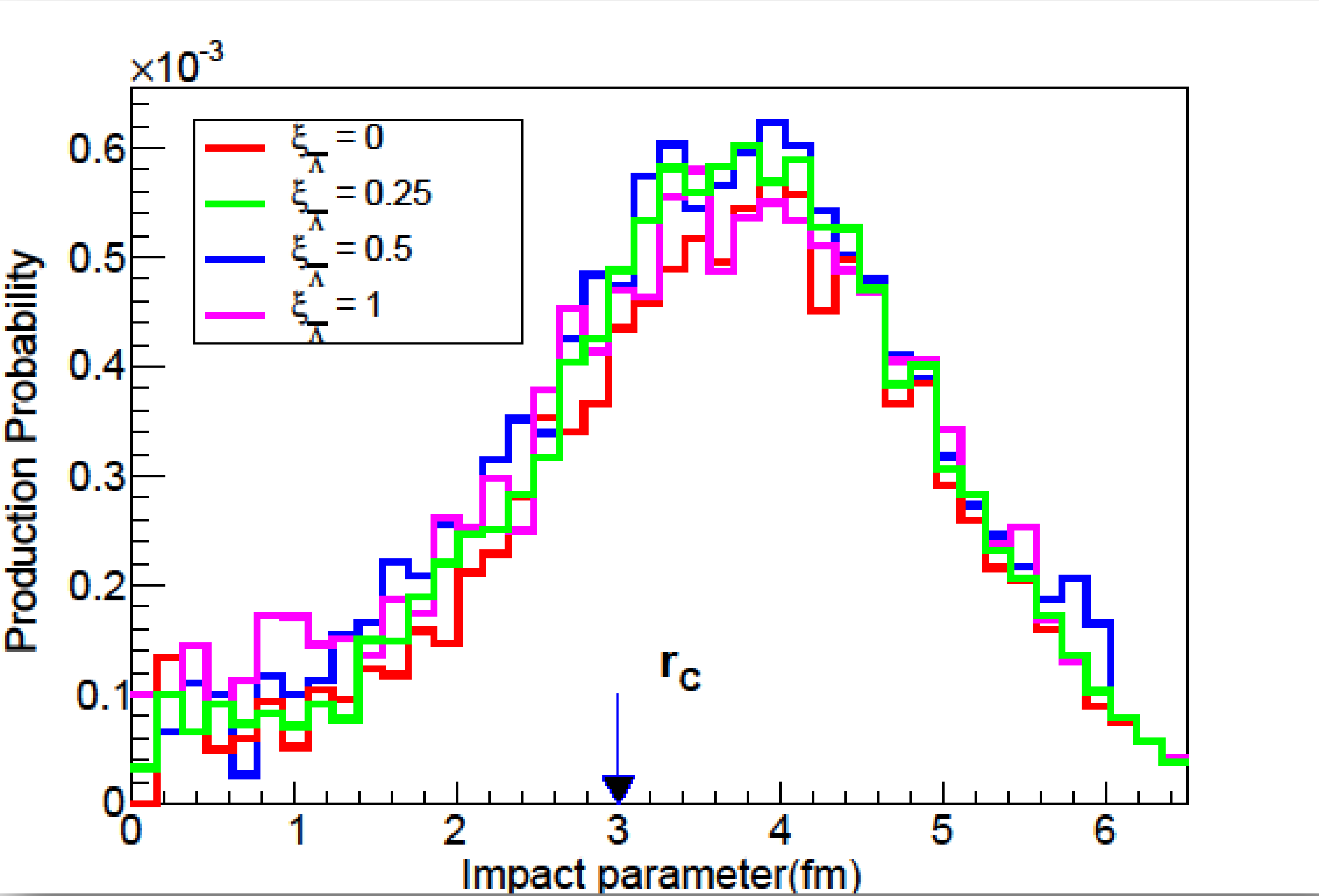
- G-parity used to estimate anti-baryons potential (except for $\bar{N}$)

TABLE I: The Schrödinger equivalent potentials of different particles at zero kinetic energy, $U_i = S_i + V_i^0 + (S_i^2 - (V_i^0)^2)/2m_i$ (in MeV), in nuclear matter at ρ_0.

i	N	Λ	Σ	Ξ	$\bar{N}$	$\bar{\Lambda}$	$\bar{\Sigma}$	$\bar{\Xi}$	K	$\bar{K}$
U_i	-46	-38	-39	-22	-150	-449	-449	-227	-18	-224

- Antiproton potential is scaled by 0.22 to obtain -150MeV

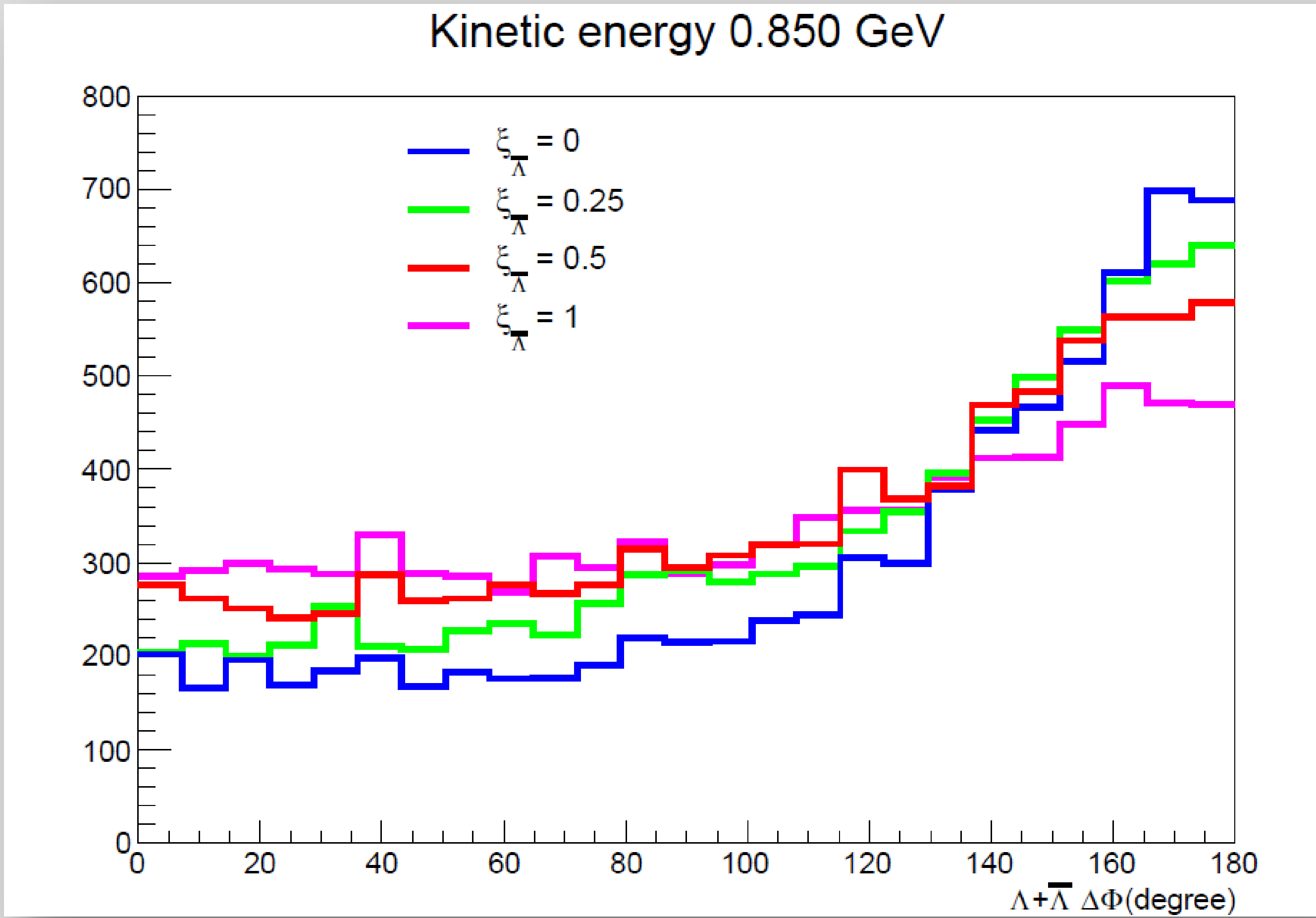
Impact Parameter



- Free $\Lambda\bar{\Lambda}$ production selects peripheral collisions

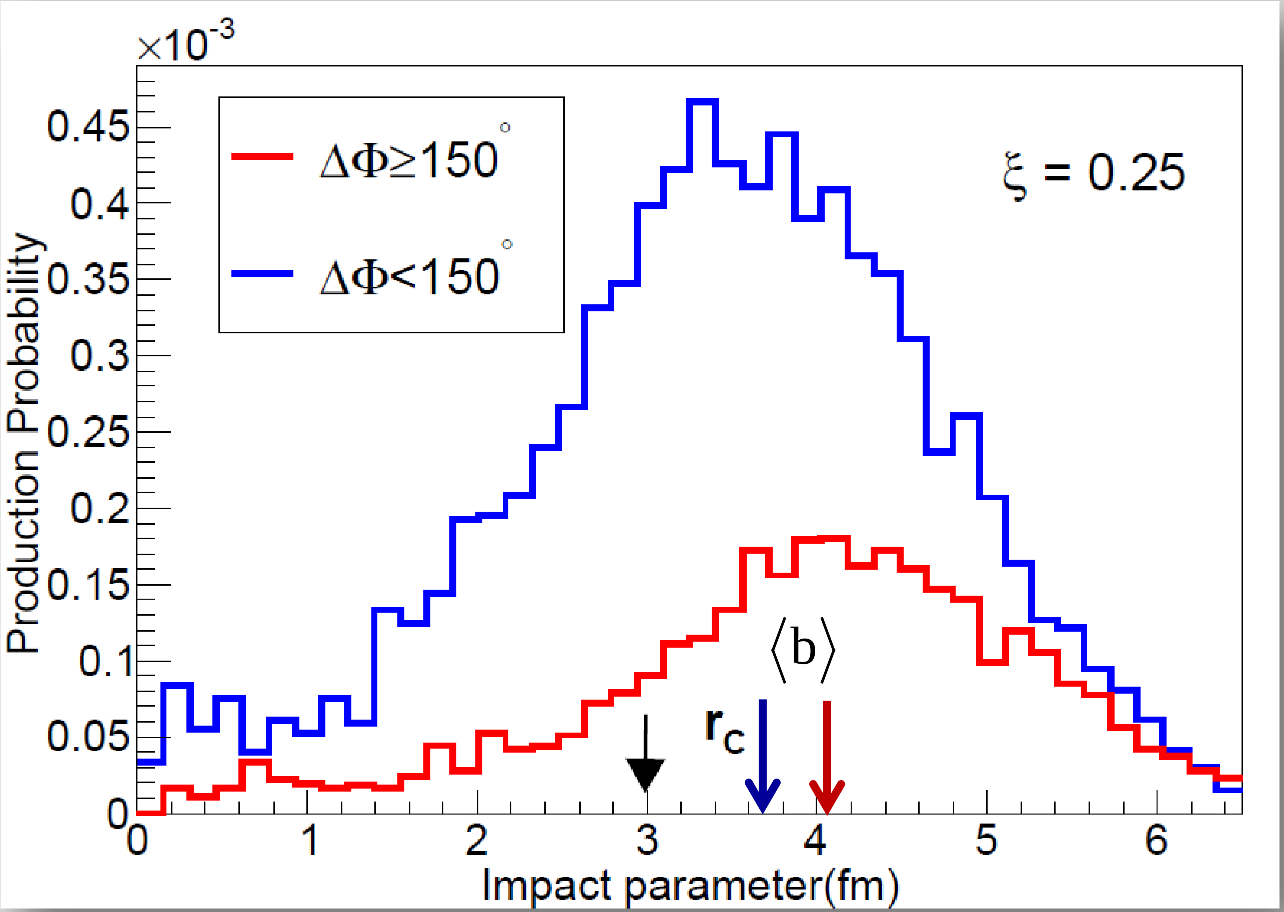
Rescattering effects

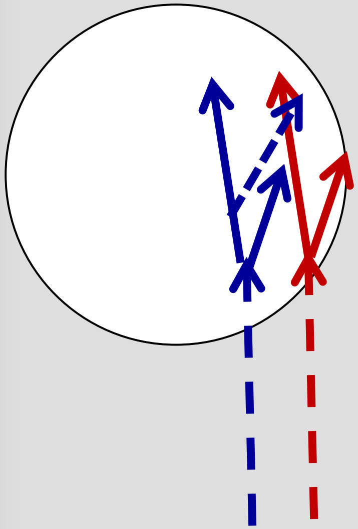
- Typical 15000 $\bar{\Lambda}\Lambda$ pairs produced



- Coplanarity distorted $\Rightarrow$ strong rescattering or refraction

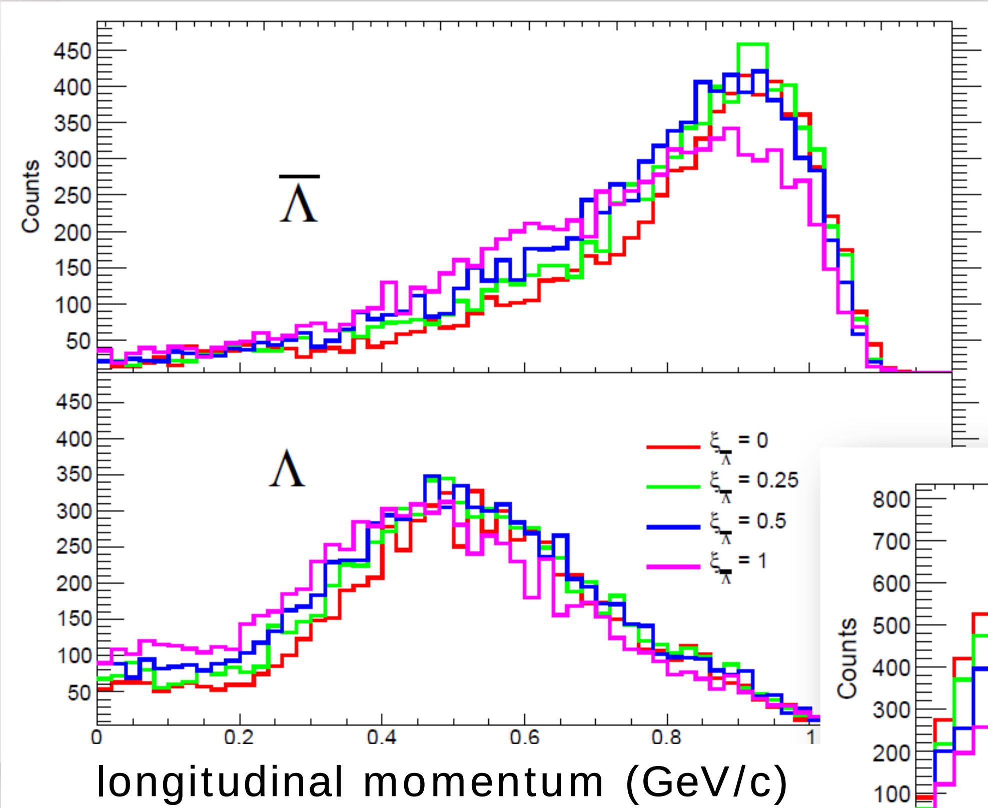
Absorption, rescattering, geometry…

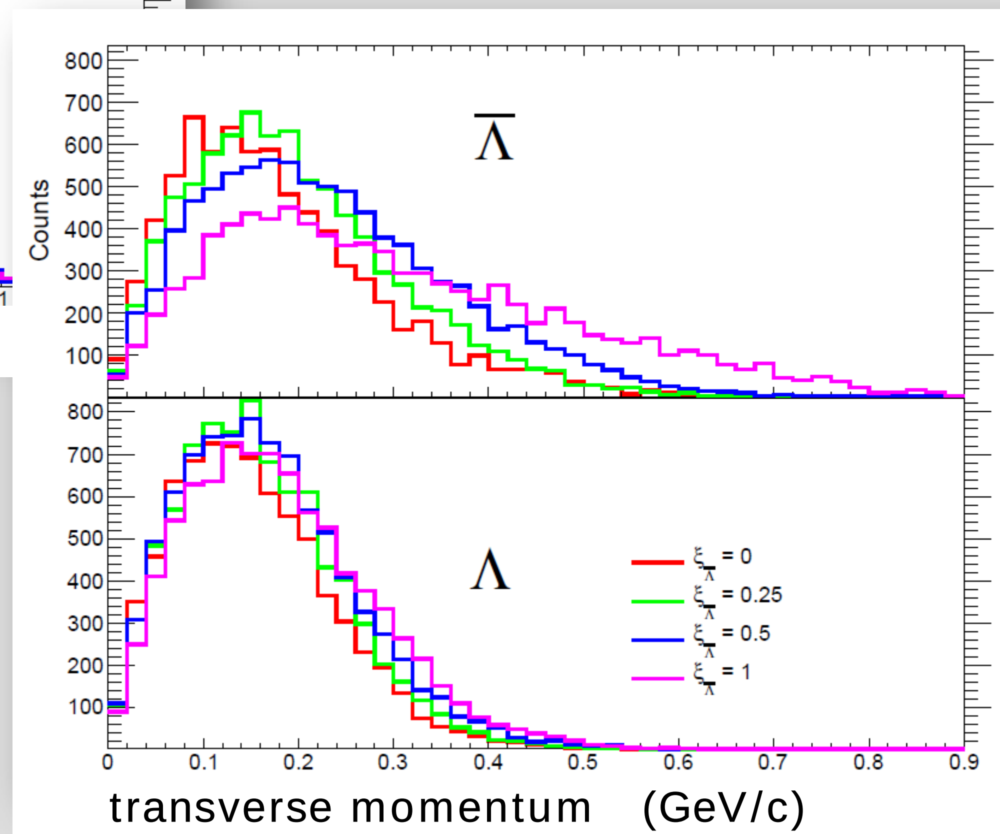




- Mikroscopic transport models needed

Rescattering & Momentum Distributions

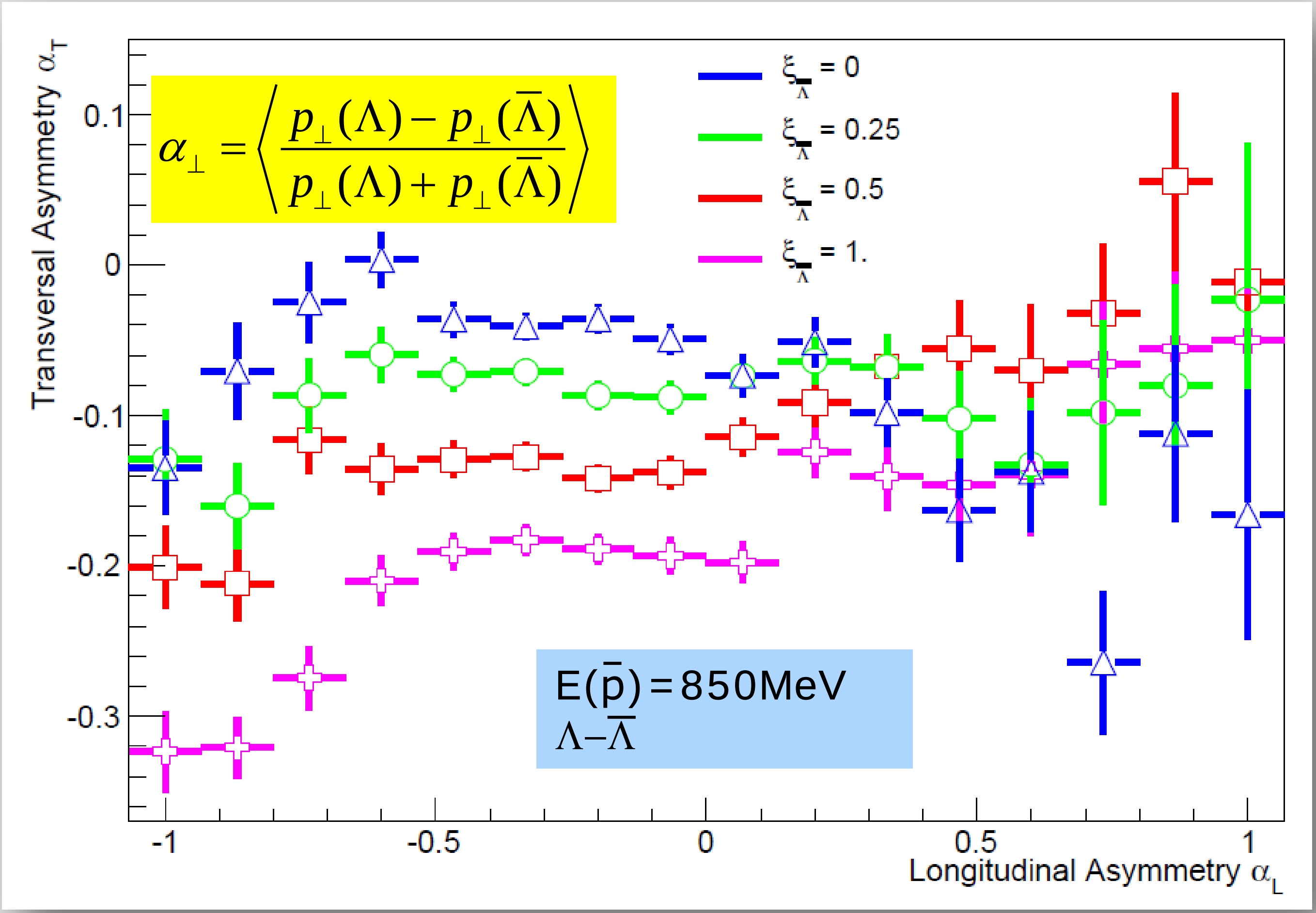


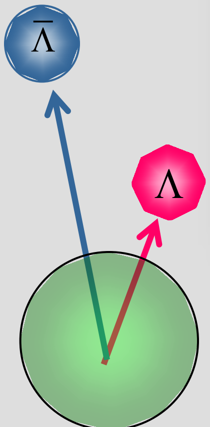


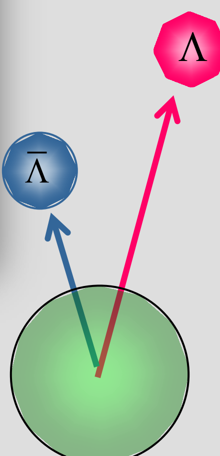
- Is $Y-\bar{Y}$ pair production at all sensitive to the $\bar{Y}$ potential ?
- Test case: Λ-$\bar{\Lambda}$ production

Scan of $\bar{\Lambda}$ Potential

- $U(\bar{\Lambda})$ = -449MeV, -225MeV, -112MeV, 0MeV
- All other potentials unchanged



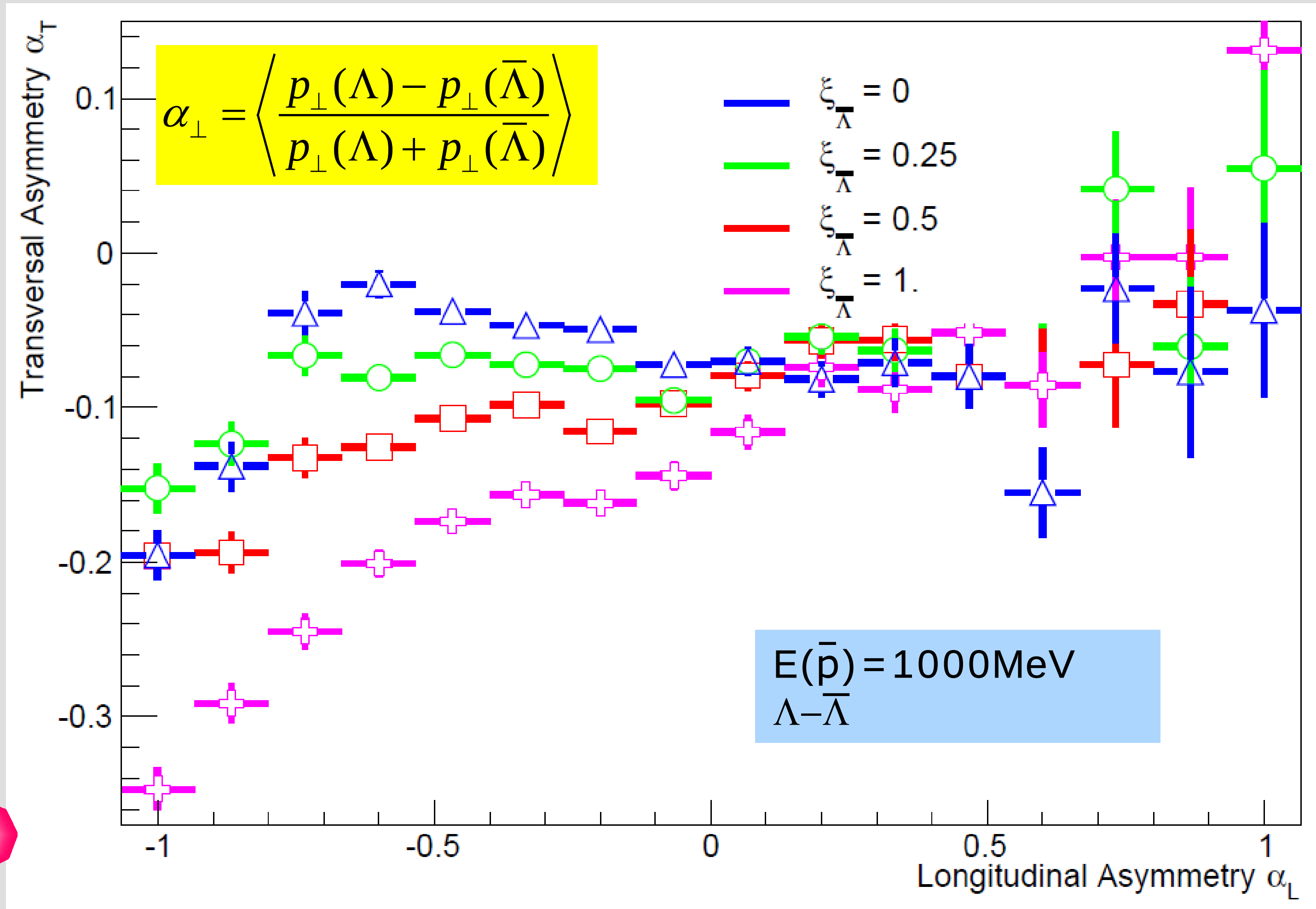


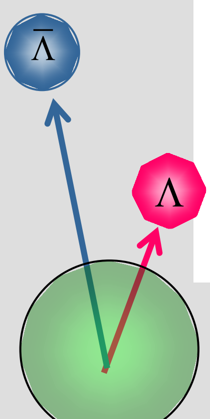


$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$

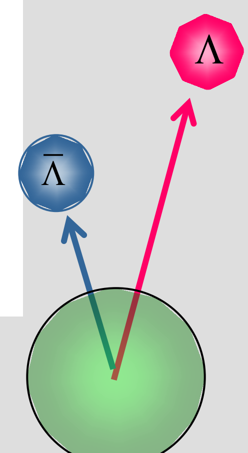
Scan of $\bar{\Lambda}$ Potential

- $U(\bar{\Lambda})$ = -449MeV, -225MeV, -112MeV, 0MeV
- All other potentials unchanged

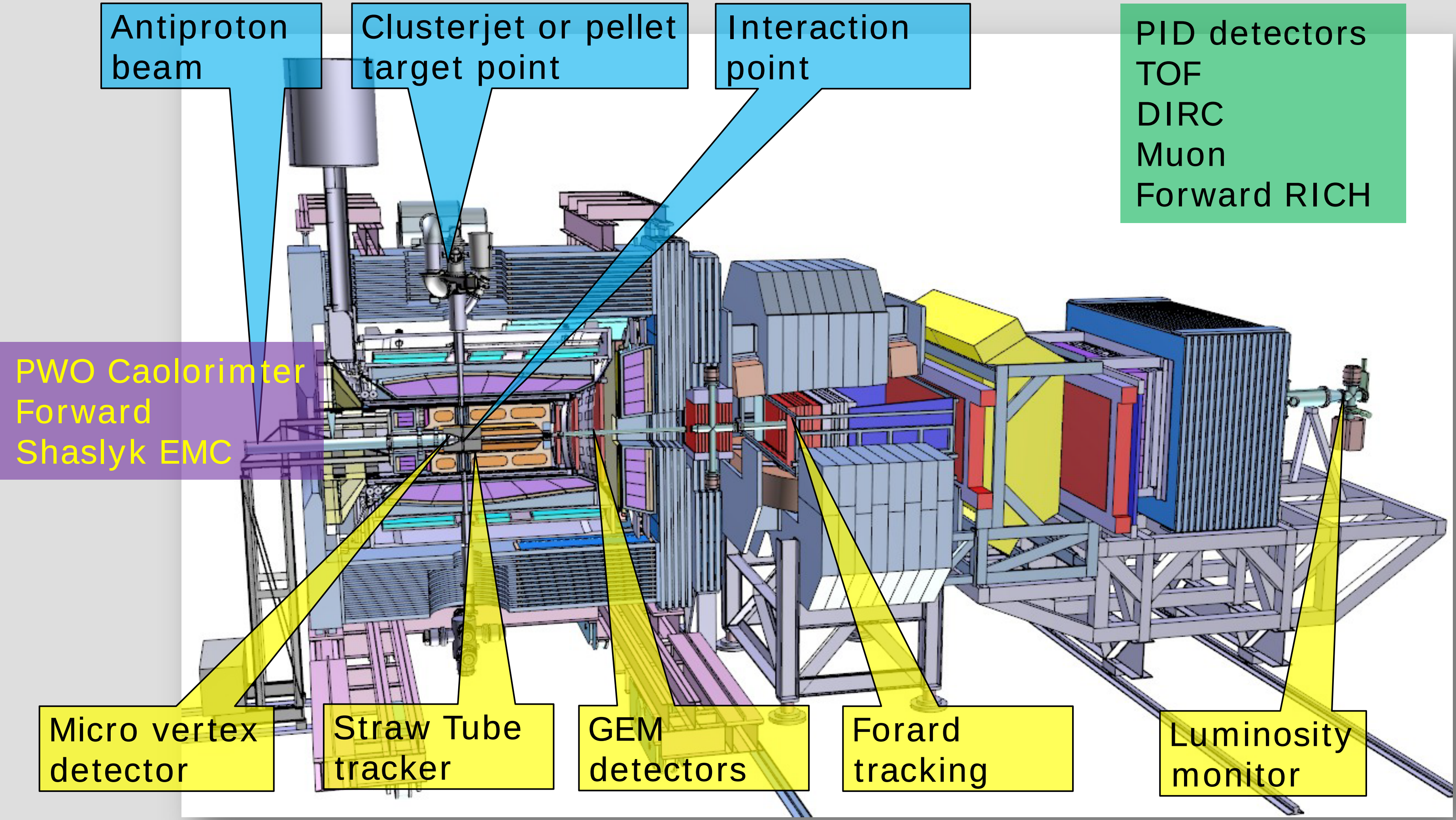




$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$



The P̄ANDA detector

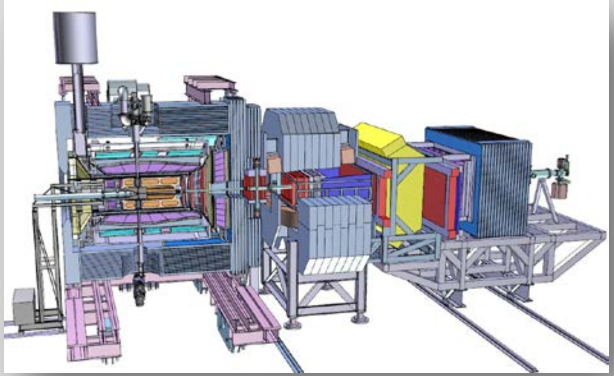


- Official timeline
  - 2013-2017: (partial) pre-assembling at COSY, Jülich
  - ≥2018: first beam expected at FAIR

Antihyperon-Hyperon Pairs in $\bar{\text{P}}$ANDA

- 2018 first beam in $\bar{\text{P}}$ANDA expected → commissioning phase
- We are right now exploring different scenarios
  - different detector availability
  - different solenoid fields (1T, 0.5T,...)

  and other important aspects like
  - luminosity
  - length of typical running period



- Typical (*preliminary*) $\bar{\Lambda}\Lambda$ pair efficiency ≈ 3-5% (better at higher momenta)
- $\bar{\Lambda}+\Lambda$ case
  - ^{nat}Ne target, H for calibration — systematic check
  - only charged particle detection — easy
  - assume average interactions rate — $10^6 s^{-1}$ (~10% of default luminosity)
  - pair reconstruction efficiency — ~3%

  ⇒ **144k detected $\bar{\Lambda}+\Lambda$ pairs per day** ⇒ **10 × GiBUU**

  - Moderate data taking period — *~14 days Ne target + 7 days p-target*

  ⇒ **130 × present GiBUU simulations**

Future Options

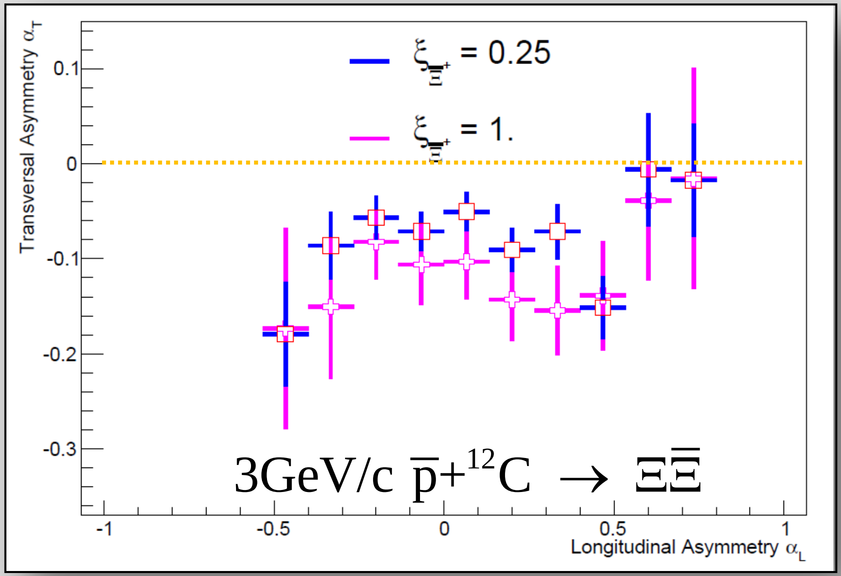
- $\overline{\Lambda}+\Sigma^-$
  - Ideal probe for interactions in the neutron skin
  - ^{20}Ne; ^{22}Ne, H for calibration; later: ^{86}Kr (36 Protons, 50 Neutrons)
  - Σ^- tracking, $\Sigma^- \rightarrow n\pi^-$
  - similar production rate (at least in light nuclei)

- Further options:
  - Any other pair: Σ-$\overline{\Sigma}$, Ξ-$\overline{\Xi}$, $\Lambda_c\overline{\Lambda}_c$
  - Long lived resonances in nuclei

    $\Lambda(1520)$ (Γ= 15.6 MeV)

    $\Xi(1530)$ (Γ=9.9 MeV)

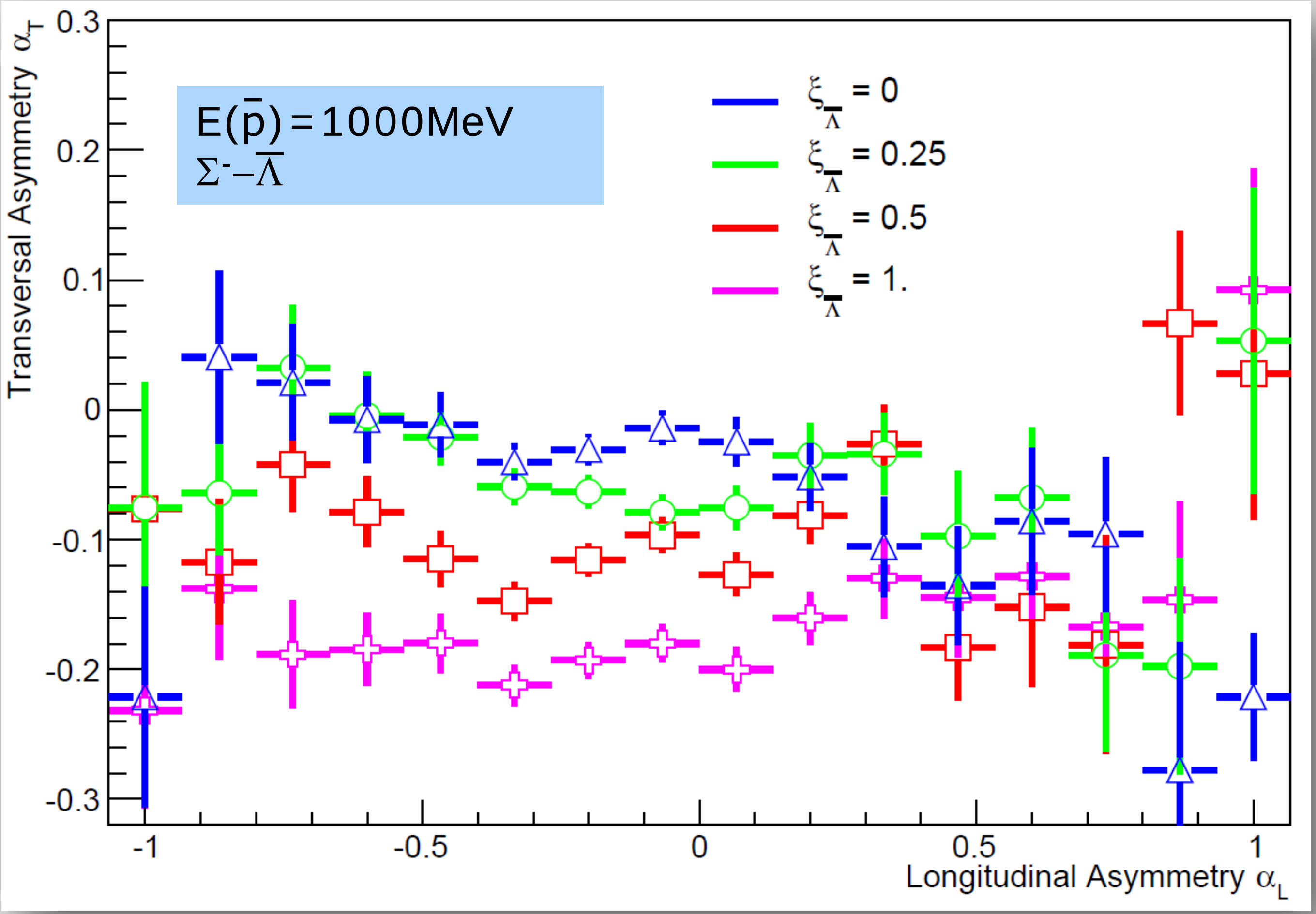
    $\Lambda_c(2880)$ (Γ=5.8MeV)



- Unique change to study charmed baryons in nuclear systems ?

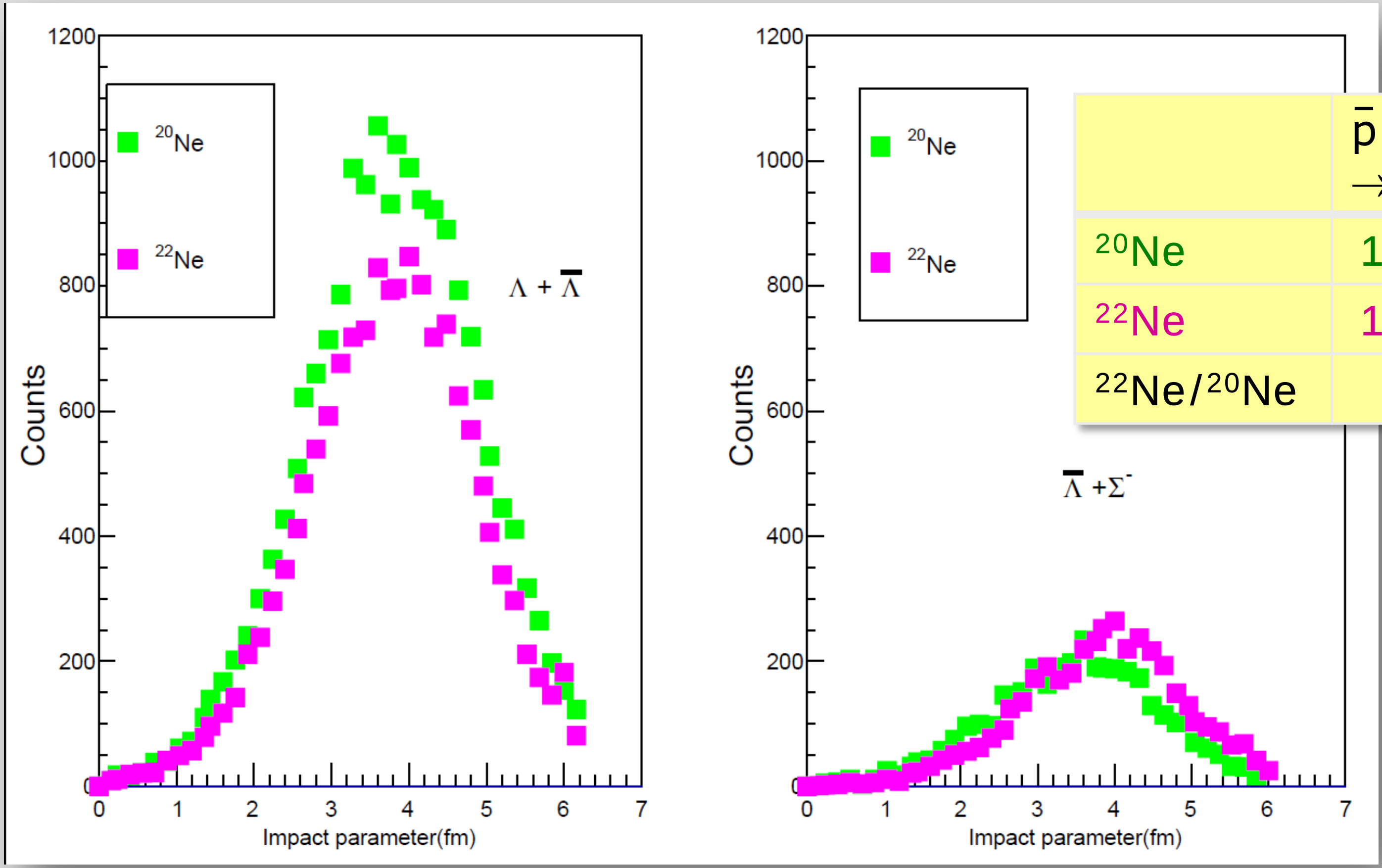
Other |s|=1 channels @ 1000MeV

- $\bar{p}+p\rightarrow\bar{\Lambda}+\Lambda$ $\bar{p}+p\rightarrow\bar{\Sigma}^0+\Lambda$
- $\bar{p}+n\rightarrow\bar{\Lambda}+\Sigma^-$ $\bar{p}+n\rightarrow\bar{\Sigma}^++\Lambda$
- all antihyperon potentials scaled by same factor



Reactions within the Neutron Skin

- 1000MeV $\bar{p}+^{20}$Ne and $\bar{p}+^{22}$Ne; $\xi(\bar{\Lambda}) = 0.25$



	$\bar{p}+p \to \bar{\Lambda}+\Lambda$	$\bar{p}+n \to \bar{\Lambda}+\Sigma^-$
^{20}Ne	18808	3667
^{22}Ne	15733	4516
^{22}Ne/^{20}Ne	0.84	1.23

- When going from ^{20}Ne to ^{22}Ne two competing effects
  - more absorption of ingoing $\bar{p}$ in thicker n-skin $\Rightarrow$ less $\bar{\Lambda}\Lambda$ and more $\bar{\Lambda}\Sigma^-$
  - more absorption of outgoing $\bar{\Lambda}$ in thicker n-skin $\Rightarrow$ less $\bar{\Lambda}\Lambda$ and less $\bar{\Lambda}\Sigma^-$
- $\bar{\Lambda}+\Sigma^-$ and $\bar{\Lambda}+\Lambda$ production may probe the neutron skin
- Possibility to explore potentials in neutron-rich environment ?

Stored antiproton beams at FAIR offer several unique opportunities to study the interactions of hyperons and antihyperons in nuclear systems

$\bar{\mathrm{P}}$ANDA is an excellent and unique factory for strange and charmed $\bar{Y}Y$ pairs

The $\bar{\Lambda}$-Λ production is an ideal experiment for the commissioning phase of $\bar{\mathrm{P}}$ANDA